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We have made significant research progress on several related aspects of our research grant during this period. 1) advanced the study of generalized chaotic synchronization schemes, 2) research on impulsive and practical impulsive control theories for chaotic systems, 3) exploring military applications of chaotic spread-spectrum communication system, 4) developing the key technologies for digitizing chaotic synchronization schemes: namely, control of chaotic systems via sampled-data feedback control, and 5) successful experimental implementation of chaotic spread-spectrum communication systems and secure communication system based on chaotic circuits and hyperchaotic circuits.

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Progress Report on ONR Grant Number N00014-97-1-0463:
"Nonlinear Dynamics for Communication Systems"
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We have made significant research progress on several related aspects of our research grant during the period July 1998 through June 1999, including 1) advanced study of generalized chaotic synchronization schemes, 2) research on impulsive and practical impulsive control theories for chaotic systems, 3) exploring military applications of chaotic spread-spectrum communication systems, 4) developing the key technologies for digitizing chaotic synchronization schemes; namely, control of chaotic systems via sampled-data feedback control, and 5) successful experimental implementation of chaotic spread-spectrum communication systems and secure communication systems based on chaotic circuits and hyperchaotic circuits.

Recently, it had been noticed that a "lossy" form of synchronization between chaotic systems, called *generalized chaotic synchronization*, is much more robust to both channel distortion and parameter drifts than conventional chaotic synchronization. Because the generalized chaotic synchronization schemes play a critical role in the chaotic secure systems, our findings that two chaotic systems can be generally synchronized via infinitely many linear synchronizing manifolds represent a major breakthrough in the theoretical research of this field. Before our work, other researchers could only use computer simulations to visualize the unknown synchronizing manifolds and could not find closed forms. This difficulty presented some major obstacles to the applications of generalized chaotic synchronization to secure communication systems. Among many are: determining 1) how many synchronizing manifolds a certain system can have, 2) what is the distance between two different synchronizing manifolds, and 3) how secure a certain generalized chaotic synchronization is. Our theoretical findings provide a definitive answer to the above questions.

In view of the advantages of chaotic impulsive synchronization over chaotic continuous synchronization, some recent progress has been made to improve many different aspects of chaotic communication systems based on impulsive synchronization.

The first aspect is the theoretical study of impulsive control theory under more general and practical conditions. In the physical world, it is impossible to get the exact parameters and noise model. To guarantee that the theoretical results can predict the performance of the whole system under realistic conditions, we need to study the stability of impulsive synchronization in a certain range, and not simply around a single equilibrium point. This kind of stability is called *practical stability*. We have successfully developed a theory to give the error range of

impulsive control algorithms under practical stability criteria. By using our theoretical results, we are now developing the theoretical basis for practical stability of impulsive synchronizations.

The second aspect is to improve the implementability of chaotic digital CDMA((CD)^{2}MA) systems by evaluating their performance under different channel conditions and different system configurations. One of the main problems is the full digitization of the entire (CD)^{2}MA system, including the chaotic core. This conversion calls into question the stability of the entire system due to the sampling process of the digital controller. We have made significant advances in developing a theoretical framework for the stability of chaotic systems under sampled-data control. We give a theory to guarantee the asymptotic stability of a chaotic system controlled by sampled-data feedback. This theory can be easily used to study the digitized chaotic synchronization schemes.

We had previously implemented a hardware test-bed for studying impulse synchronization experimentally. Based on this hardware experimental platform we found many exciting results. First, we experimentally verified that impulsive synchronization is much more robust than its continuous counterparts to noise and parameter drifts. Second, we have observed the successful impulse synchronization between two *hyperchaotic* systems through a single synchronizing channel. Third, different chaotic secure communication schemes and spread-spectrum communication schemes were successfully implemented in this single test-bed. Since hyperchaotic systems can provide much more security in a chaotic communication system, our experimental results on the impulsive chaotic communication systems based on hyperchaotic systems are very important for future research.

Our future research will combine our above cited results with impulse radio systems that use impulses with sub-nanosecond duration as a carrier.

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